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REPORT

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**DIGITAL  $Y_2$ ,  $(U \pm V)$ :  
further tests**

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### Summary

*The digital  $Y_2$ ,  $(U \pm V)$  system is an efficient way of distributing a colour television signal in digital form and could be used as an international exchange standard.*

*This report describes subjective tests which show that, when using an analogue YUV input, the system can produce better PAL and SECAM signals than conventional analogue coders. The tests also confirm the results of earlier tests<sup>1</sup> which showed that, when operating with a PAL input, good quality SECAM pictures can be obtained; alternatively, the original PAL signals can be re-formed essentially unchanged.*

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## DIGITAL $Y_2, (U \pm V)$ : FURTHER TESTS

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### 1. Introduction

Digital  $Y_2, (U \pm V)^*$  is an efficient way of digitally encoding the luminance and chrominance components of a colour television signal.<sup>1</sup> The luminance component ( $Y$ ) is digitised at a sampling rate of twice the PAL colour subcarrier frequency ( $2f_{sc}$ ). The two chrominance components ( $U$  and  $V$ ) are combined to give a single digital signal ( $U \pm V$ ) consisting of ( $U + V$ ) and ( $U - V$ ) on alternate television lines. The chrominance sampling frequency is at present  $f_{sc}$  but it may be possible to reduce this to  $2f_{sc}/3$  or even to  $f_{sc}/2$  without serious loss.

This system could be used for international exchange of colour television signals as illustrated in Fig. 1. Digital  $Y_2, (U \pm V)$  signals would always travel on the international network and could be combined to give a PAL signal for transmission to

PAL viewers, or converted to analogue  $YUV$  which can be easily coded into SECAM. There would then be no need for a receiving country to insert PAL to SECAM or SECAM to PAL transcoders at any time.

Digital  $Y_2, (U \pm V)$  can be generated from analogue  $YUV$  signals where these are available. Alternatively, a PAL source may be used; this is important because most broadcasters who use PAL in their studios expect to continue to do so for a long time to come. The  $Y_2, (U \pm V)$  signals obtained from  $YUV$  and PAL sources are superficially very similar. But, the signals obtained from PAL sources inevitably contain crosstalk between PAL luminance and chrominance components as described in section 2.2. Because of these differences it is necessary to test each of the possible routes through the system.

When a PAL source is used, the  $Y_2, (U \pm V)$  system not only gives good SECAM pictures, despite the effective PAL to SECAM transcoding (Fig. 1, route 3), but it also allows the original

\* In reference (1) the system was called ( $Y_s, U + V/U - V$ ); this has now been shortened to  $Y_2, (U \pm V)$ . It is also sometimes referred to as the 'Weston' system.

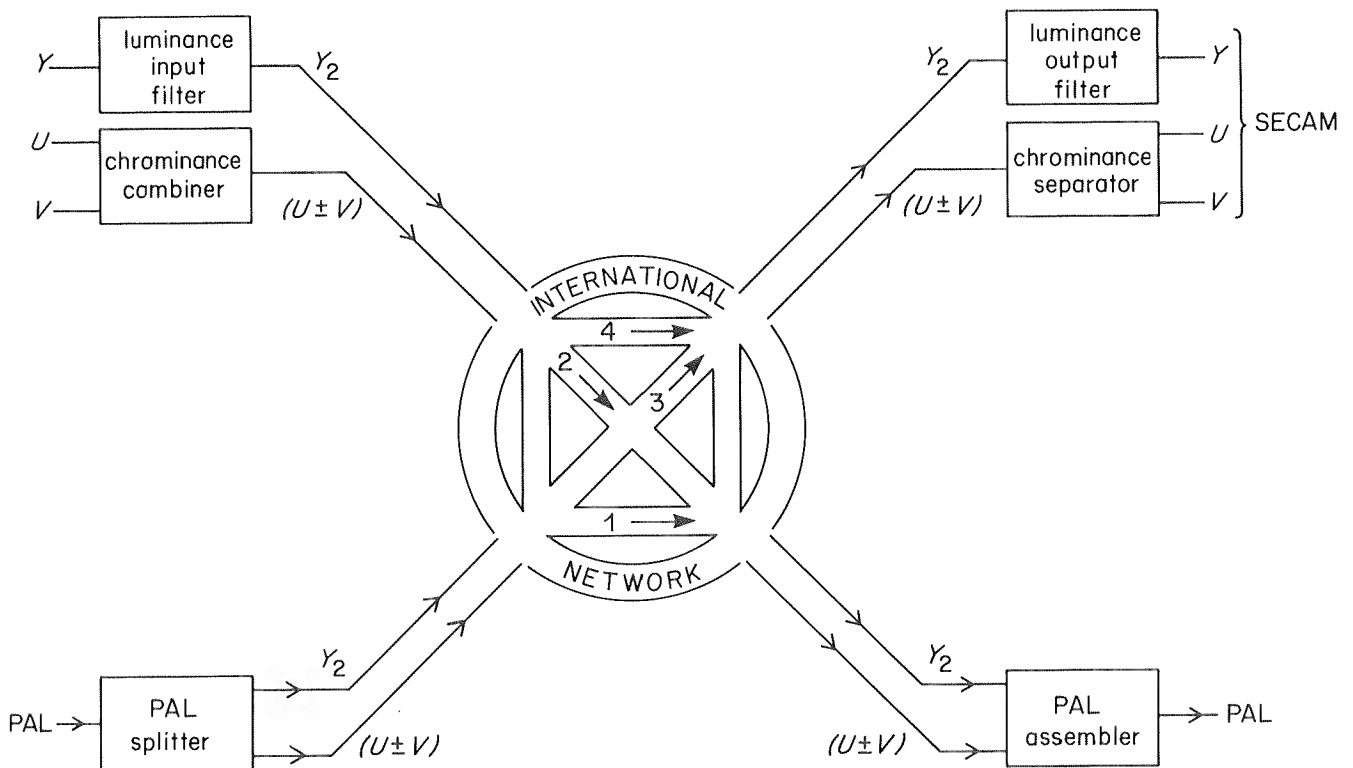


Fig. 1 - International Exchange

PAL signal to be re-formed essentially unchanged (route 1), so that transmissions of PAL signals from one PAL country to another, via the international network, would not suffer from the PAL splitting and recombining operations involved. These two properties of the digital  $Y_2$ , ( $U \pm V$ ) system, operating with a PAL source, were confirmed in a set of subjective tests described in a previous report<sup>1</sup>.

When that report was written, the experimental equipment could only accept a PAL source, but it has now been extended to accept an analogue  $YUV$  source. Further tests have been conducted to assess the quality of the analogue  $YUV$ , SECAM and PAL signals obtained via the digital  $Y_2$ , ( $U \pm V$ ) system from analogue  $YUV$  as well as from PAL sources. These subjective tests are described in Section 3 of this report. But first, Section 2 explains the observed characteristics of each route.

## 2. System characteristics

The next four subsections summarise the most important properties of the system without repeating the detailed descriptions contained in the previous report<sup>1</sup>. The numbering of the routes is the same as has been used for previous public demonstrations, but it is more convenient to describe them in reverse order.

### 2.1 Route 4 . . . $YUV \rightarrow Y_2$ , ( $U \pm V$ ) $\rightarrow YUV$ ( $\rightarrow$ SECAM)

The luminance component is sampled at  $2f_{sc}$ . This would normally give rise to aliasing of the upper part of the band ( $\sim 3.3 - 5.5$  MHz) but this is reduced by comb filters at input and output which remove odd harmonics of half the line frequency (high-frequency diagonals). The simple comb filters used, each having only 1 line delay, leave some (attenuated) residual alias at odd harmonics of quarter-line frequency. SECAM coders contain fairly wide notch filters which mask these effects. Indeed, the small loss of luminance detail further reduces SECAM crosscolour to a small extent.

The chrominance signals are sampled at  $f_{sc}$ . This gives ample horizontal resolution and it may be possible to reduce this sampling frequency without ill effects.

The  $U$  and  $V$  signals are combined to form a single signal consisting of  $U + V$  and  $U - V$  on alternate T.V. lines. At the receiving end, they are

separated by averaging the signals from successive lines to give  $U$ , and subtracting signals from successive lines to give  $\pm V$ . Crosstalk between  $U$  and  $V$  can produce flickering horizontal chrominance edges (e.g. on horizontal colour bars) but this is greatly reduced by pre-filtering the  $U$  and  $V$  signals before combination. The main effects on chrominance are thus to produce flickering, softened, horizontal chrominance edges.

This slight softening of horizontal chrominance edges reduces the visibility of SECAM chrominance "hop", replacing it with the flicker caused by residual crosstalk between  $U$  and  $V$ , which is less noticeable, especially at large viewing distances.

### 2.2 Route 3 . . . PAL $\rightarrow Y_2$ , ( $U \pm V$ ) $\rightarrow YUV$ ( $\rightarrow$ SECAM)

The  $YUV$  signals obtained from a PAL source via the  $Y_2$ , ( $U \pm V$ ) system contain all the above effects together with the unavoidable luminance/chrominance crosstalk inherent in PAL. This crosstalk is however slightly different from that produced by conventional analogue delay-line PAL decoding.

Because the  $Y_2$ , ( $U \pm V$ ) system separates PAL into  $Y_2$  and ( $U \pm V$ ) by means of a comb filter, 'vertical' luminance components (e.g. test-card resolution bars) do not produce chrominance patterns (crosscolour) as they would in a conventional PAL decoder. Offsetting this, 'diagonal' luminance components, having frequencies which lie around odd harmonics on half the line frequency give slightly more crosscolour. 'Diagonal' luminance components have a higher spatial frequency and are thus less likely to occur than 'vertical' luminance components (with the same horizontal pitch). So crosscolour is on the whole slightly reduced. However, diagonal luminance components produce crosscolour patterns which appear to crawl downwards. Since on random fine detail this downwards crawl is not matched by the upward crawl of patterns produced by other luminance components, the resulting crosscolour can be more annoying.

The  $Y_2$ , ( $U \pm V$ ) system removes subcarrier patterning much more effectively and over a much wider band than the luminance notch in a conventional decoder. There is thus virtually no residual subcarrier patterning on plain areas, and vertical colour bar edges are much cleaner. This freedom from subcarrier patterning allows the output to be coded directly into SECAM without generating beats between the PAL and SECAM subcarriers. Subcarrier patterning does, however,

remain on horizontal chrominance edges. In the previous tests these components were attenuated by an additional narrow 12 dB notch filter included in the system output, before SECAM coding, to cope with problems caused by low-level residual PAL-subcarrier breakthrough in plain areas. This residual breakthrough has now been eliminated by improvements to the instrumentation and the narrow notch was not used in the present tests.

### 2.3 Route 2 . . . $YUV \rightarrow Y_2, (U \pm V) \rightarrow PAL$

When decoded by a conventional delay-line decoder, the PAL signals obtained from  $YUV$  via the  $Y_2, (U \pm V)$  system produce far less crosscolour than normally coded PAL. There are two reasons for this. Firstly, the comb filters used in the  $Y_2, (U \pm V)$  system attenuate high-frequency diagonal luminance components which would otherwise cause crosscolour. In particular, odd harmonics of half the line frequency are completely removed.

The coarsest and therefore most annoying crosscolour patterns are caused by odd harmonics of quarter the line frequency. The comb filters attenuate these components by only 6 dB but the remaining coarse crosscolour is completely cancelled out by the residual alias caused by  $2f_{sc}$  sampling.

This second beneficial effect of the  $Y_2, (U \pm V)$  system is best explained by considering  $U$  crosscolour separately from  $V$  crosscolour. Coarse crosscolour patterns on the  $U$  output are produced by luminance components which are a quarter of line frequency below harmonics of line frequency, i.e.  $f = (n - \frac{1}{4})f_h$ , where  $n$  is an integer and  $f_h$  is line frequency. Each component of the luminance input may be treated as a vector rotating in the  $U/V$  phase diagram (Fig.2). Sampling at  $2f_{sc}$  produces a counter-rotating alias vector which, at odd harmonics of quarter line frequency, has the same amplitude as the wanted output and gives a resultant along the  $V$  axis. This is ignored by the  $U$  axis synchronous demodulator in the decoder\* and does not reach the  $V$  axis demodulator in a delay-line PAL decoder because of the comb filter formed by the delay line. The alias at  $(n + \frac{1}{4})f_h$  is in antiphase with that at  $(n - \frac{1}{4})f_h$  and so luminance components at  $(n + \frac{1}{4})f_h$ , which would normally give coarse crosscolour patterns in the output, produce a resultant along the  $U$  axis which is ignored by the decoder.

Thus when  $Y_2, (U \pm V)$  signals obtained from a  $YUV$  source are encoded into PAL the loss of diagonal luminance resolution and the residual

\* Provided that the reference subcarrier is correctly phased.

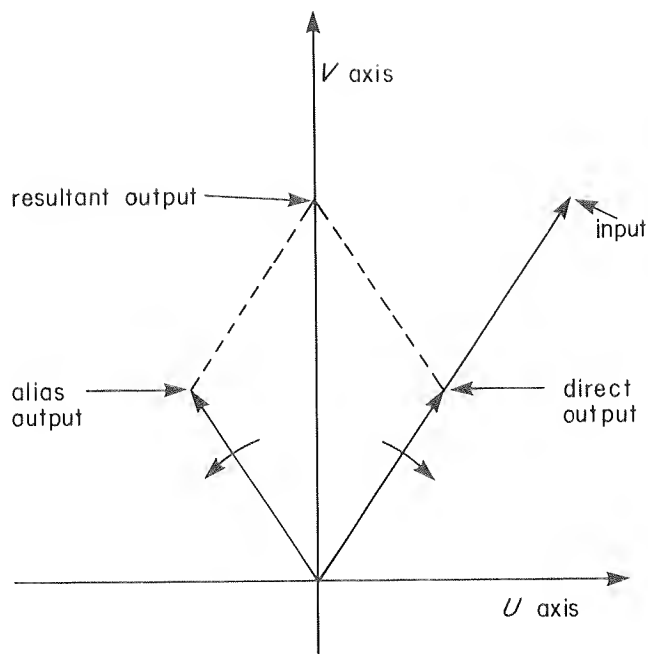


Fig. 2 - Effect on  $2f_{sc}$  sampling on luminance phase ( $f = (n - \frac{1}{4})f_h$ )

aliasing inherent in the  $Y_2, (U \pm V)$  system prevent the generation of the coarsest crosscolour and reduce fine crosscolour. Odd harmonics of quarter the line frequency and of half the line frequency produce no crosscolour. Harmonics of line frequency produce the normal amount. (Note that decoding via  $Y_2, (U \pm V)$ , i.e. via route 3) would ignore these components and there would be no luminance/chrominance crosstalk whatsoever, not even residual crosstalk at frequencies other than the harmonics of quarter the line frequency. However, this is outside the scope of this present report).

When  $YUV$  signals are coded into PAL via the  $Y_2, (U \pm V)$  system the  $U$  and  $V$  components suffer the same vertical resolution losses and crosstalk effects as in the  $YUV \rightarrow Y_2, (U \pm V) \rightarrow YUV$  route. However delay line PAL decoding of the resulting PAL signal further softens horizontal chrominance edges and reduces the visibility of the  $U/V$  crosstalk flicker.

### 2.4 Route 1 . . . $PAL \rightarrow Y_2, (U \pm V) \rightarrow PAL$

As mentioned in the Introduction,  $Y_2, (U \pm V)$  signals obtained from a PAL source can be recoded to give a PAL output which is almost identical with the original PAL input. The effects mentioned in the previous Sections cancel out. This is possible because the splitting of PAL to give  $Y_2, (U \pm V)$  does not throw away any information. Any

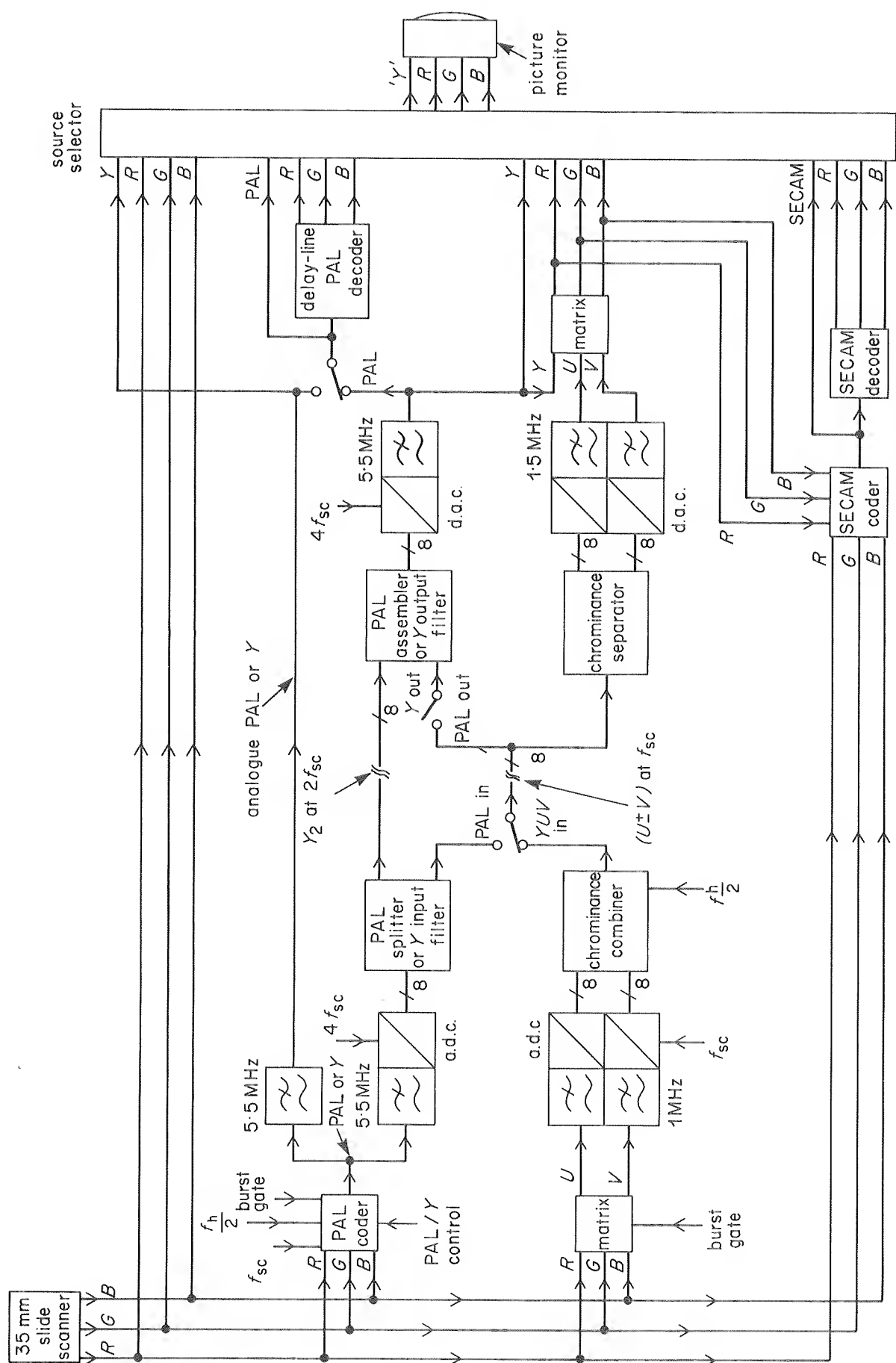


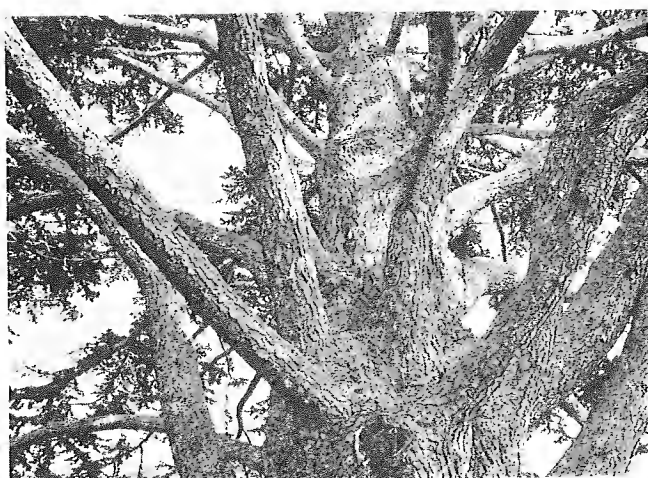
Fig. 3 - Test equipment block diagram



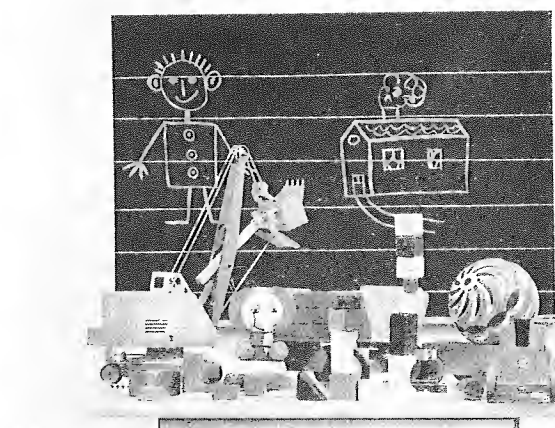
(a)



(b)



(c)



(d)

*Fig. 4 - Test pictures - monochrome versions*

(a) Girl (b) Boats (c) Tree (d) Blackboard

information not carried in the  $Y_2$  signal is carried by the  $(U \pm V)$  signal and vice versa.

In the present instrumentation of the system the 'transparency' of the  $PAL \rightarrow Y_2$ ,  $(U \pm V) \rightarrow PAL$  route is limited by the performance of the band-pass filters used to define the 3.36 – 5.5 MHz chrominance band. These filters leave residual effects at the band edge (i.e. where the filters have neither unity nor zero response). Since the present system was constructed it has been realised that this is not fundamental and that it would be possible to obtain perfect recombination even with imperfect filters.

### 3. Subjective tests

These tests were conducted to assess the quality of the  $YUV$ ,  $SECAM$  and  $PAL$  signals obtained via the digital  $Y_2$ ,  $(U \pm V)$  system from either a  $YUV$  or a  $PAL$  source. Analogue  $RGB$  and conventionally coded and decoded  $SECAM$  and  $PAL$  were used as controls.

#### 3.1 Equipment

A block diagram of the experimental arrangement is shown in Fig. 3.

$RGB$  signals were obtained from a flying-spot

35mm slide scanner, with horizontal and vertical aperture correction and logarithmic masking. Fig. 4 shows monochrome versions of the 4 slides used.

A PAL coder\*, from which the chrominance could be removed to give  $Y$ , together with an  $(RGB \rightarrow U, V)$  matrix provided either PAL or  $YUV$  signals which were 'digitised' and then converted to the  $Y_2$ ,  $(U \pm V)$  form. The resulting digital  $Y_2$ ,  $(U \pm V)$  signals were then either combined to give PAL or separated to give  $YUV$  which (after matrixing to  $RGB$ ) could be viewed directly or via a SECAM coder and decoder. Conventional delay-line PAL decoding was used where appropriate.

The pictures were displayed on either a high-quality 22" colour or a 19" monochrome monitor. The peak brightness of the monitors was adjusted to be 70 cd/m<sup>2</sup> (20 ft. lamberts); the ambient illumination reflected from the screen was less than 1 cd/m<sup>2</sup>.

### 3.2 Test procedure

A total of 10 expert observers took part in the tests, in 2 groups of 5. Three were seated at five-times picture-height (and asked not to lean forward). The other two were seated at seven-times picture-height (and allowed to lean forward if they wished).

In each test session (which took about 25 minutes) the observers were shown 40 test pictures (for about 20 seconds each) and asked to grade each picture using the 5-point impairment scale.

\* The PAL coder did not have a crosscolour-reducing luminance notch filter.

Grade	Degree of Impairment
5	Imperceptible
4	Perceptible, but not annoying
3	Slightly annoying
2	Annoying
1	Very annoying

Two slides were used (alternately) in each session. Analogue ( $RGB$ ) pictures were shown before each session and the first four tests were ignored. The rest of the tests were in random order, each condition being shown twice with each slide, to check for inconsistencies.

### 3.3 Results

Tables 1 and 2 give the averaged results of 20 assessments of each combination of slide and signal-route. The overall standard deviation of the votes from their respective means was 0.64. The standard error is thus 0.14. (one vote was discarded because it was more than 2 grades from the mean).

#### 3.3.1 Colour

The results show that good pictures can be obtained via the digital  $Y_2$ ,  $(U \pm V)$  system. Despite the slight resolution losses, residual aliases and  $U/V$  crosstalk effects described in Section 2.1 the  $YUV \rightarrow Y_2$ ,  $(U \pm V) \rightarrow YUV$  route was graded only 0.37 of a grade worse than  $RGB$  and, because of its freedom from crosscolour, 0.23 of a grade better than analogue PAL coding and decoding. The  $YUV \rightarrow Y_2$ ,  $(U \pm V) \rightarrow PAL$  route

Table 1 — Colour Results

No.	Route	Slide	(a) Girl	(b) Boats	(c) Tree	(d) Blackboard	Mean
	Analogue $RGB$		4.95	4.90	4.80	4.80	4.86
4	$YUV \rightarrow Y_2$ , $(U \pm V) \rightarrow YUV$		4.25	4.70	4.58	4.43	4.49
3	$PAL \rightarrow Y_2$ , $(U \pm V) \rightarrow YUV$		4.43	4.20	3.35	4.30	4.07
	Analogue PAL		4.33	4.68	3.88	4.13	4.26
2	$YUV \rightarrow Y_2$ , $(U \pm V) \rightarrow PAL$		4.35	4.60	4.53	4.43	4.49
1	$PAL \rightarrow Y_2$ , $(U \pm V) \rightarrow PAL$		4.48	4.60	3.78	4.35	4.30
	Analogue SECAM		3.75	4.05	3.68	3.75	3.82
4 <sub>s</sub>	$YUV \rightarrow Y_2$ , $(U \pm V) \rightarrow YUV \rightarrow SECAM$		4.25	4.15	4.13	3.85	4.10
3 <sub>s</sub>	$PAL \rightarrow Y_2$ , $(U \pm V) \rightarrow YUV \rightarrow SECAM$		3.68	4.03	3.08	3.03	3.46

Table 2 — Monochrome Results

No.	Route	Slide	(a) Girl	(b) Boats	(c) Tree	(d) Blackboard	Mean
	Analogue Y		4.83	4.85	4.70	4.75	4.78
4	$YUV \rightarrow Y_2, (U \pm V) \rightarrow Y$		4.65	4.68	4.78	4.80	4.73
3	$PAL \rightarrow Y_2, (U \pm V) \rightarrow Y$		4.63	4.80	4.75	4.38	4.64
	Analogue PAL		3.23	3.80	4.35	3.48	3.72
2	$YUV \rightarrow Y_2, (U \pm V) \rightarrow PAL$		3.20	3.63	4.23	3.50	3.64
1	$PAL \rightarrow Y_2, (U \pm V) \rightarrow PAL$		3.18	3.67	4.25	3.33	3.61
	Analogue SECAM		3.50	3.50	3.68	3.03	3.43
4 <sub>s</sub>	$YUV \rightarrow Y_2, (U \pm V) \rightarrow YUV \rightarrow SECAM$		3.60	3.80	4.13	3.18	3.68
3 <sub>s</sub>	$PAL \rightarrow Y_2, (U \pm V) \rightarrow YUV \rightarrow SECAM$		3.20	3.33	3.45	3.03	3.25

produced some fine crosscolour on 'Boats' and 'Tree' but, compared to the  $YUV \rightarrow Y_2, (U \pm V) \rightarrow YUV$  route, the additional effect of the delay line PAL decoder reduced the visibility of vertical chrominance flicker on 'Girl' and 'Blackboard'. The overall grade was thus the same as for  $YUV \rightarrow Y_2, (U \pm V) \rightarrow YUV$ ; i.e. 0.23 of a grade better than analogue PAL coding and decoding which produced annoying coarse crosscolour on 'Tree'.

As expected,  $PAL \rightarrow Y_2, (U \pm V) \rightarrow PAL$  was not significantly different from analogue PAL.  $PAL \rightarrow Y_2, (U \pm V) \rightarrow YUV$  was on average slightly worse than analogue coding and decoding. This was due mainly to more visible downward-crawling crosscolour on 'Boats' and 'Tree'.

$PAL \rightarrow Y_2, (U \pm V) \rightarrow YUV \rightarrow SECAM$  was only 0.36 of a grade worse than analogue SECAM despite the combination of PAL and SECAM effects.  $YUV \rightarrow Y_2, (U \pm V) \rightarrow YUV \rightarrow SECAM$  was 0.32 of a grade better than analogue SECAM because of its reduced chrominance hop and reduced SECAM crosscolour.

### 3.3.2 Monochrome

When viewed on a monochrome monitor, the Y and PAL signals obtained via the  $Y_2, (U \pm V)$  system were not very different from conventional analogue Y and PAL. ( $PAL \rightarrow Y_2, (U \pm V) \rightarrow Y$  left some subcarrier patterning on horizontal chrominance edges but the result was only 0.14 of a grade worse than analogue Y).

The SECAM pictures showed more variation;  $PAL \rightarrow Y_2, (U \pm V) \rightarrow YUV \rightarrow SECAM$  was 0.18 of a grade worse than analogue SECAM.  $YUV \rightarrow Y_2, (U \pm V) \rightarrow YUV \rightarrow SECAM$  was 0.25 of a grade better than analogue SECAM.

## 4. Conclusions

$Y_2, (U \pm V)$  is an efficient way of digitally encoding colour television signals and could form the basis of an internationally agreed digital-coding standard.

Subjective tests have shown that, when operating with a YUV input the system produces better PAL and SECAM pictures than conventional analogue PAL and SECAM coders. Good SECAM pictures can also be obtained from a PAL input. PAL signals pass through the system virtually unchanged.

## 5. References

1. WESTON, M. 1976. A PAL/YUV digital system for 625-line international connections. BBC Research Department Report No. 1976/24.

